Inquiry into the distribution of fluoride in the environment of Garrison, Montana

Charles Kay
The University of Montana

AN INQUIRY INTO THE DISTRIBUTION OF FLUORIDE

IN THE ENVIRONMENT OF GARRISON, MONTANA

By

Charles Edward Kay

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Approved by:

W. Leslie Pengelly

Chairman, Board of Examiners

John M. Stewart

Dean, Graduate School

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INTRODUCTION

Studies and investigations (Carlson and Dewey, 1971; Carlson, 1972; Gordon, 1967, 1968, 1972, 1972a; Hodge and Smith, 1965) have demonstrated that atmospheric fluoride contamination accumulates in vegetation which, when consumed by wild and domestic animals, may cause fluorosis, thereby resulting in damage to grazing wildlife and livestock populations (Gordon, 1967a, 1968a, 1969; Marier and Rose, 1971). The Montana State Department of Health standards state that it is illegal to cause fluoride accumulations of greater than 35 ppm (parts per million) in forage (dry weight basis). The purpose of this study was to delineate the distribution of fluoride in the environment of Garrison, Montana, through the collection and analysis of native floral and faunal species.

Garrison, Montana, was selected for this fluoride survey due to the previous fluoride pollution problems caused there by the operation of Rocky Mountain Phosphates, Inc., a phosphate rock defluorination plant that produces an animal food supplement (U.S. Department of Health, Education, and Welfare, 1967). In the past, Montana courts have dictated that fluoride emissions from this source (hereafter denoted only as RMP) must be reduced because of the environmental damages which have occurred as a result of those emissions (Gordon, 1970, for a chronological record of RMP). By again investigating the fluoride concentrations in indigenous plants and animals from Garrison, the effectiveness of the pollution control efforts of RMP may be demonstrated. Throughout the entire period of study, RMP was at 99.9 percent fluoride emission control, emitting two to three pounds of fluoride per day as hydrogen fluoride gas from the stack at the point source (personal communication from Mr. Bryce Rhodes, President of RMP, 1971 and 1972).

METHODS

A. Description of Area

For a detailed discussion of topography, vegetation, climate, or weather patterns of the Garrison area refer to: United States Department of Health, Education, and Welfare, 1967.

B. Field Study Design

Within the vicinity of Garrison, thirty study areas were chosen based upon land ownership and land use patterns, vegetational communities, and distance from RMP (Figure 1). Inside each study area a varying number of collection points was randomly chosen based upon area size and the diversity of flora present. Collection sites were chosen so that as large a variety of species as possible was obtained.

In order to maintain a constant sampling base, all collections were identified and processed by species. Consolidation into general classes of vegetation, such as forage, was done to facilitate statistical analysis, only after the completion of fluoride analysis.

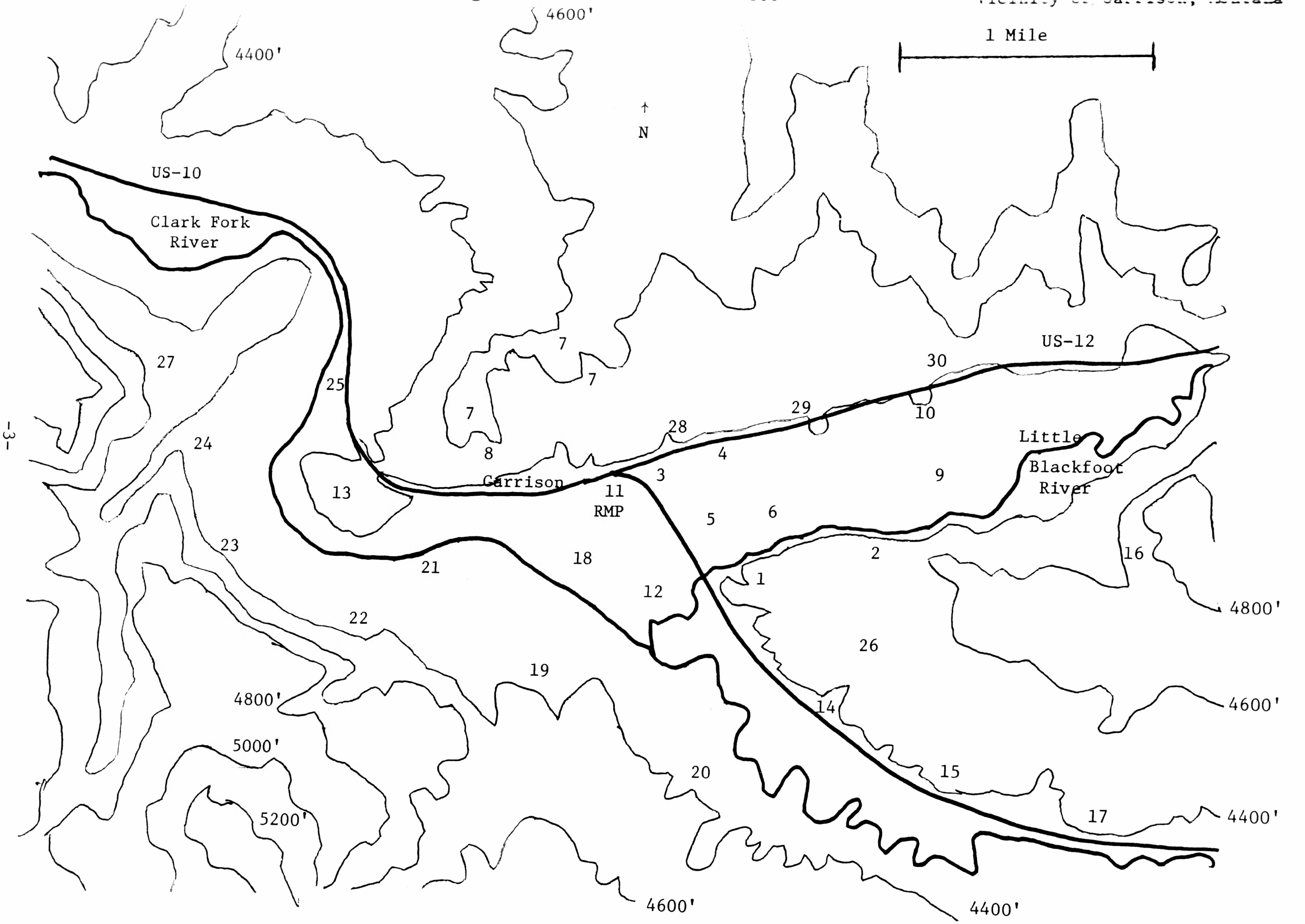
C. Collection of Samples

Approximately 800 samples were collected in October of 1971 and 1972.

Plants

Forage samples such as grasses and alfalfa were taken by cutting arbitrarily selected plants at one inch above ground level to insure that entire specimens were acquired and to insure the lack of selection for the top or bottom of the plants (Ledbetter, et al., 1960). Cottonwood, Douglas fir, and ponderosa pine foliage samples were collected from the RMP-facing upper one-half of trees by shooting branches down with a twelve-gauge shotgun.

Vicinity of Garrison, Montana



Where possible, fallen cottonwood leaves were also collected. Immediately upon collection, all samples were placed in individually numbered paper bags. A description of the enumerated collection site and other necessary data were recorded in the researcher's diary for future reference.

Animals--Small Mammals

Animal specimens were acquired by the use of snaptraps and/or livetraps baited with a mixture of peanut butter and rolled oats (Mosby, 1963). Collection sites consisted of 10 to 40 traps laid out in a grid configuration, or, where terrain was steep, a linear trap pattern was employed.

All small mammals were individually tagged and placed in plastic BAGGIES. The tag number, a description of the trap site, and other relevant information was noted in each researcher's field journal.

D. Separation of Samples

Conifers

Upon receipt at the laboratory, conifer needles were removed from their branches and separated according to year of growth (Gordon, 1970). Because conifers leaf out during the month of May in the Garrison area, it is possible to observe fluoride accumulation over various exposure times:

Exposure Period	Exposure Time
Current year's growth	5 months
One-year-old growth	17 months
Two-year-old growth	29 months

The growth of juniper was not separated by year, and hence this species represents a composite sample exposed over an undetermined period of time. The scale-like leaves were separated from the stems after drying, although the complete exclusion of all woody material was impossible.

Crested Wheatgrass

Cognizance of the fact that bunchgrasses are resistant to weathering (Gordon, 1970a) allows one to separate the vegetation of crested wheatgrass plants accordingly:

Sample	Exposure Time
Composite	weighted average
One-year-old growth	17 months
Current year's growth	5 months
Fall green-up	1 month

Deciduous Trees and Forage Plants

All other species collected, including both deciduous trees and forage plants, represent tissue growth from approximately May 1st to the date of sampling and, therefore, reflect the severity of fluoride pollution during that period.

After being handled in accordance with the above guidelines, all plant material was placed in appropriately numbered paper bags which were then inserted into a forced draft oven.

Small Animal Specimens

Both femurs were dissected out, placed in numbered glass beakers, and boiled in an Alconox solution to remove all flesh.

E. Sample Preparation and Fluoride Analysis

A detailed description of the techniques for sample preparation and fluoride analysis used in this study are presented in: Gordon, 1972; Kay, 1972; Kay, et al., 1973. Fluoride activity was determined with an ORION Fluoride Specific Ion Electrode (Jacobson and Heller, 1970; Singer and Armstrong, 1968). An excess of all plant material was stored for future analysis.

RESULTS AND DISCUSSION

A. Control Data

Before one is able to delineate the extent of fluoride contamination in an ecosystem by using indigenous vegetation and mammals, it is obvious that normal levels of fluoride in plant and animal tissue must be known. In this regard, sampling of control, non-polluted flora and fauna was undertaken throughout the state of Montana. Two hundred and forty-one plant samples and one hundred small animal samples were analyzed chemically for fluoride. These data are presented in Table 1.

In most instances, control vegetation samples averaged less than 5 ppm fluoride and in no case over 10 ppm fluoride. Therefore, plant averages below 10 ppm fluoride are classed as controls. This is in agreement with the published findings of other researchers (Carlson and Dewey, 1971; Gordon, 1972; McCune and Hitchcock, 1970).

The total average for all small mammals was 156.7 ppm fluoride with the average for rodents being 127.1 ppm. Individual animals, except shrews, seldom had an excess of 300 ppm fluoride in their femurs. For these reasons, average values in excess of 200 ppm fluoride will be employed to indicate a polluted region; those less than 200 ppm fluoride will be designated as unpolluted. Again, this is in agreement with published data on native indigenous mammals (Gordon, 1972).

B. Contamination by Study Areas

Information on fluoride contaminations in the Garrison area is presented by species and study area in Tables 2 and 3, 1971 and 1972 data respectively. Species values represent averages of a variable sample size, forage is the average of all grass and forb species, and total plant is the mean of all

TABLE 1--CONTROL DATA--PLANT AND ANIMAL SPECIES

SPECIES	N*	$\bar{X}$	SD	CV	SE $\bar{X}$	EXE $\bar{X}$
Alfalfa, once cut (*Medicago sativa*)	1	6.4				
Alfalfa, uncut	3	4.9	1.9	39.1	1.1	22.6
Bluebunch Wheatgrass (*Agropyron spicatum*)	22	5.7	2.5	44.2	0.5	9.4
Cottonwood (*Populus trichocarpa*)	7	6.4	1.8	27.7	0.6	10.4
Crested Wheatgrass (*Agropyron cristatum*)						
Composite	3	5.9	0.4	7.4	0.2	4.3
17 months	2	5.6	3.4	60.6	2.4	42.8
5 months	2	5.8	2.0	34.1	1.4	24.1
1 month	2	5.6	3.1	55.6	2.2	39.2
Douglas Fir (*Pseudotsuga menziesii*)						
41 months	4	3.1	0.5	16.2	0.2	8.1
29 months	13	3.1	1.1	37.1	0.3	10.3
17 months	13	3.2	1.0	31.6	0.3	8.7
5 months	13	3.3	1.4	43.6	0.4	12.1
Grass--various species	38	3.8	1.6	42.9	0.3	7.0
Hay--various species	4	4.2	1.4	33.9	0.7	16.9
Juniper (*Juniperus scopularum*)	12	4.4	2.4	55.2	0.7	15.9
Lilac (*Syringa vulgaris*)	1	4.0				
Ponderosa Pine (*Pinus ponderosa*)						
53 months	5	1.6	0.7	45.7	0.3	20.4
41 months	13	3.0	1.7	57.7	0.5	16.0
29 months	26	3.3	2.1	64.4	0.4	12.6
17 months	27	2.7	1.4	52.7	0.3	10.1
5 months	27	2.5	1.2	46.2	0.2	8.9
Smooth Brome Grass (*Bromus inermus*)	3	3.8	1.3	33.8	0.7	19.6
Total Plants	241	3.9	1.5	38.5	0.2	5.2
Forage--grasses & forbs	72	4.5	2.1	46.1	0.2	5.3
Chipmunk (*Eutamias sp.*)	19	103.1	70.5	68.4	16.2	15.7
Deer Mouse (*Peromyscus maniculatus*)	70	143.8	65.8	45.7	7.8	5.4
Meadow Vole (*Microtus sp.*)	5	136.6	62.8	45.9	28.1	20.5
Shrew (*Sorex sp.*)	6	493.8	201.7	40.8	82.3	16.7

N* = Sample Size
$\bar{X}$ = Mean
SD = Standard Deviation
CV = Coefficient of Variation in Percent
SE $\bar{X}$ = Standard Error of the Mean
EXE $\bar{X}$ = Experimental Error of the Mean in Percent

TABLE 2--AVERAGE PPM FLUORIDE BY STUDY AREAS FOR ALL PLANT AND ANIMAL SPECIES--1971*

Study	AS	AC				DF			PP			C	BI	G	A	Al	L	J	H	TP	F	LM	S	M	CH
Area		C	17	5	1	29	17	5	29	17	5														
1	100	115	111	92	33	121	91	105	48	38	16	-	-	-	36	-	-	116	-	79	95	1595	-	-	-
2	24	-	-	-	-	32	22	20	-	-	-	-	-	-	-	-	-	-	-	24	24	731	-	-	-
3	-	-	-	-	-	-	-	-	-	-	-	102	24	-	74	20	58	-	16	48	28	-	-	-	-
4	-	-	-	-	-	-	-	-	-	-	-	51	11	-	30	21	-	-	-	30	23	-	-	-	-
5	-	-	-	-	-	-	-	-	-	-	-	104	64	47	66	-	-	-	33	76	57	-	10,500	-	-
6	-	-	-	-	-	-	-	-	-	-	-	23	11	-	21	20	-	-	-	19	15	-	-	-	-
7	41	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	83	-	48	41	-	-	-	-
8	88	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	177	-	116	88	-	-	-	-
9	-	-	-	-	-	-	-	-	-	-	-	18	11	-	-	-	-	-	-	15	11	-	-	-	-
10	-	-	-	-	-	-	-	-	-	-	-	-	9	-	-	26	-	-	-	14	14	-	-	-	-
11	-	-	250	74	66	-	-	-	-	-	-	470	54	-	-	-	-	-	-	178	111	-	-	-	-
12	-	-	-	-	-	-	-	-	-	-	-	86	43	-	54	46	94	-	-	64	42	-	-	-	541
13	74	-	-	-	-	63	70	31	-	-	-	-	-	50	-	-	-	76	-	64	70	-	-	-	-
14	64	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	64	64	-	-	-	-
15	38	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	38	37	-	-	-	-
16	10	-	-	-	-	7	12	10	-	-	-	-	-	-	-	-	-	-	-	10	10	288	-	-	-
17	23	-	-	-	-	-	-	-	-	-	-	-	-	13	-	-	-	20	-	17	21	878	2715	750	730
18	-	-	-	-	-	-	-	-	-	-	-	121	-	28	-	-	-	200	-	66	28	-	-	-	-
19	-	-	-	-	-	11	11	6	-	-	-	9	-	6	-	-	-	11	6	8	6	401	-	-	-
20	-	-	-	-	-	8	7	10	4	4	4	6	-	7	-	-	-	9	-	6	7	-	-	-	-
21	-	-	-	-	-	-	-	-	-	-	-	23	-	7	-	-	-	54	-	18	7	451	1315	353	-
22	-	-	-	-	-	33	18	16	-	-	-	12	-	10	-	-	-	28	6	18	9	346	-	-	-
23	-	-	-	-	-	18	17	15	-	-	-	-	-	7	-	-	-	28	-	17	7	-	-	-	-
24	-	-	-	-	-	11	10	7	8	8	8	-	-	5	-	5	12	17	5	10	5	474	-	-	-
25	-	-	-	-	-	-	-	-	-	-	-	-	-	18	-	-	-	-	-	18	18	-	-	-	-

*For explanation of abbreviations see end of Table 3.

TABLE 3--AVERAGE PPM FLUORIDE BY STUDY AREAS FOR ALL PLANT AND ANIMAL SPECIES--1972*

Study	AS	AC				DF			PP			C	BI	G	A	A1	L	J	H	TP	F	DM	S	M	CH
Area		C	17	5	1	29	17	5	29	17	5														
1	93	66	158	40	43	383	252	261	-	-	-	102	58	45	127	42	-	190	-	116	67	1222	2555	-	1914
2	36	-	-	-	-	31	32	27	-	-	-	-	-	-	-	-	-	-	-	31	35	1179	-	-	-
3	-	-	-	-	-	-	-	-	-	-	-	57	17	-	19	-	57	-	-	38	19	-	-	-	-
5	-	214	-	-	-	-	-	-	-	-	-	-	182	-	225	187	-	-	-	200	198	-	-	-	-
7	85	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	97	-	86	85	-	-	-	-
8	64	-	-	-	-	-	-	-	-	-	-	-	-	-	-	47	-	79	-	72	61	-	-	-	-
11	-	122	154	107	46	-	-	-	-	-	-	687	96	-	-	-	-	-	-	456	109	-	-	-	-
12	-	-	-	-	-	-	-	-	-	-	-	172	105	-	92	50	83	-	-	123	91	896	-	-	420
13	40	-	-	-	-	32	60	44	-	-	-	-	-	-	-	-	-	-	-	62	44	-	-	-	-
14	-	-	-	-	-	-	-	-	-	-	-	-	-	-	39	-	-	204	-	27	30	-	-	-	-
15	19	-	-	-	-	-	-	-	-	-	-	16	10	-	-	-	-	-	-	16	15	-	-	-	-
17	-	-	-	-	-	-	-	-	-	-	-	12	11	-	-	-	-	-	-	18	11	-	-	-	-
18	-	-	-	-	-	-	-	-	-	-	-	66	-	18	-	-	-	38	-	41	17	-	-	-	-
20	-	-	-	-	-	14	17	9	-	-	-	11	14	-	25	-	-	-	-	14	19	-	-	-	-
22	-	-	-	-	-	-	-	-	-	-	-	25	13	-	18	-	-	-	-	17	15	-	-	-	-
23	-	-	-	-	-	-	-	-	-	-	-	-	6	-	18	-	-	-	-	11	11	-	-	-	-
24	-	-	-	-	-	-	-	-	15	9	6	-	-	-	-	-	-	-	-	6	-	-	-	-	-
25	-	19	34	18	23	-	-	-	-	-	-	21	20	-	18	12	-	-	-	18	21	-	-	-	-
26	39	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	38	38	-	-	-	-
27	16	-	-	-	-	23	24	16	-	-	-	-	-	-	-	-	-	-	-	16	16	-	-	-	-
28	52	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	51	51	-	-	-	-
29	27	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	26	26	-	-	-	-
30	23	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	23	22	-	-	-	-

*AS = Bluebunch Wheatgrass
AC = Crested Wheatgrass--C-Composite, 17 month exposure time, 5 month exposure time, 1 month exposure time
DF = Douglas Fir--29 month exposure time, 17 month exposure time, 5 month exposure time
PP = Ponderosa Pine--29 month exposure time, 17 month exposure time, 5 month exposure time
C = Cottonwood
BI = Smooth Brome Grass
G = Grass
A = Alfalfa--uncut, 5 month exposure time
A1 = Alfalfa--once cut, 2 month exposure time
L = Lilac
J = Juniper
H = Hay
TP = Total Plant
F = Forage
DM = Deer Mouse
S = Shrew
M = Meadow Vole
CH = Chipmunk

vegetation samples collected within the individual study area.

It is clear from these tables that the Montana state standard for fluoride in forage, 35 ppm, was being violated in the Garrison vicinity in both 1971 and 1972. However, because the enumeration of the study areas in Tables 2 and 3 follows no geographical pattern, it is impossible to determine the exact land acreage so contaminated and violated or if RMP is the fluoride source. Answers to these two points can be and were obtained by examining the directional matrix of fluoride accumulation.

C. Directional Pattern of Fluoride Accumulation in Vegetation

Patterns of fluoride accumulation in indigenous flora are most readily explained by the movement of air masses and the topographic features that direct or channel those air masses (Gordon, 1972). The reader is again referred to Figure 1 to note the contour lines and the landforms that they imply and to U.S. Department of Health, Education, and Welfare, 1967, for information on Garrison's weather systems.

From the data supplied in the above publication, five directions were chosen for computations: north, east, southeast, southwest, and west northwest. When a single line did not intersect a representative number of study areas, an angle was employed. Only values for forage were included in the calculations, since the Montana state standard for fluoride in vegetation is based only on forage.

Figure 2, RMP--north, shows that the state standard of 35 ppm fluoride in forage was being violated in October, 1971, to a distance of 1/2 mile north from RMP and 7/8 mile distance in the fall of 1972. Further, decreasing fluoride contamination with increasing distance from RMP implies that its operations are responsible for the fluoride pollution in a northerly direction (Magill, 1956).

Figure 1. Ppm Fluoride in Forage, Plotted from RMP--North

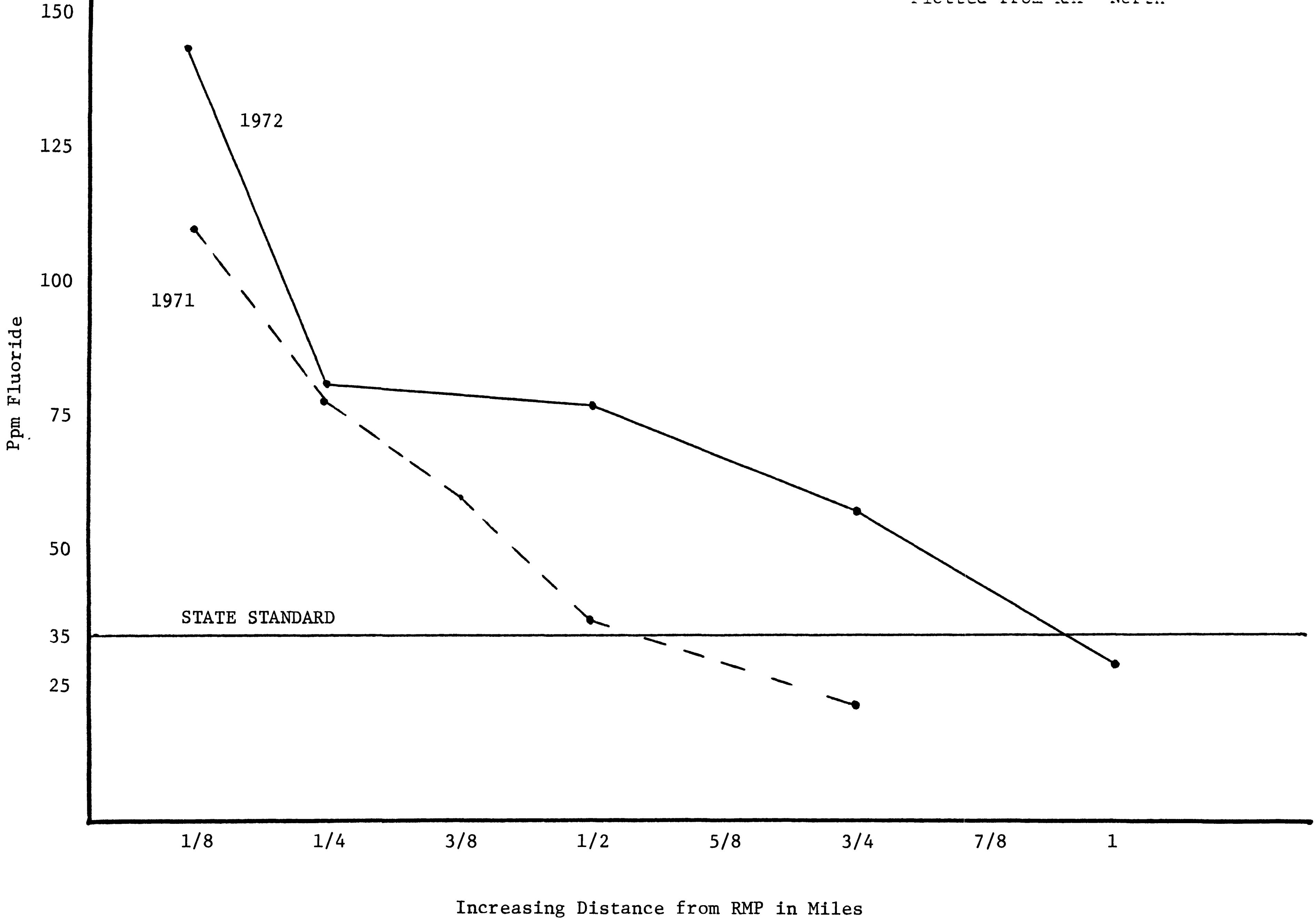


Figure 3, RMP--east, shows that though there was fluoride contamination (above 10 ppm) for 1-1/4 miles in an easterly direction in 1971, the levels of fluoride are below the state's allowable limit. Since we are dealing almost entirely with gaseous fluoride (U.S. Department of Health, Education, and Welfare, 1967), this is interpreted as indicating that there are few strong air flows from the west. In 1972, the contamination was approximately double the previous year's levels. Again, fluoride levels decrease with increasing distance from RMP.

Figure 4, RMP--southeast, indicates that the state standard of 35 ppm fluoride is being exceeded to a distance of 1-5/8 miles southeast of RMP, and that pollution (over 10 ppm fluoride) is occurring at least 2-1/8 miles southeast of RMP. Conclusively then, there appear to be strong or numerous air flows from the northwest and, as before, decreasing fluoride concentration with increasing distance from RMP.

Figure 5, RMP--southwest, as indicated by concentrations of fluoride that are below the 10 ppm control level, shows there is extremely little air movement southwestward.

Figure 6, RMP--west and northwest, emphasizes two major atmospheric conditions: cold air inversions and cold air drainages down both the Little Blackfoot and Clark Fork Rivers (U.S. Department of Health, Education, and Welfare, 1967). The fluoride values near the plant, though elevated, are below the state standard, which would tend to indicate limited air movement from the east. However, the concentrations of fluoride which rise sharply with increasing distance west from RMP are the result of topography exposing the vegetation, since inversions prevent plume dispersal, and cold air drainage abuts the inversions and the undispersed plume up against the hills.

Figure 3. Ppm Fluoride in Forage, Plotted from RMP--East

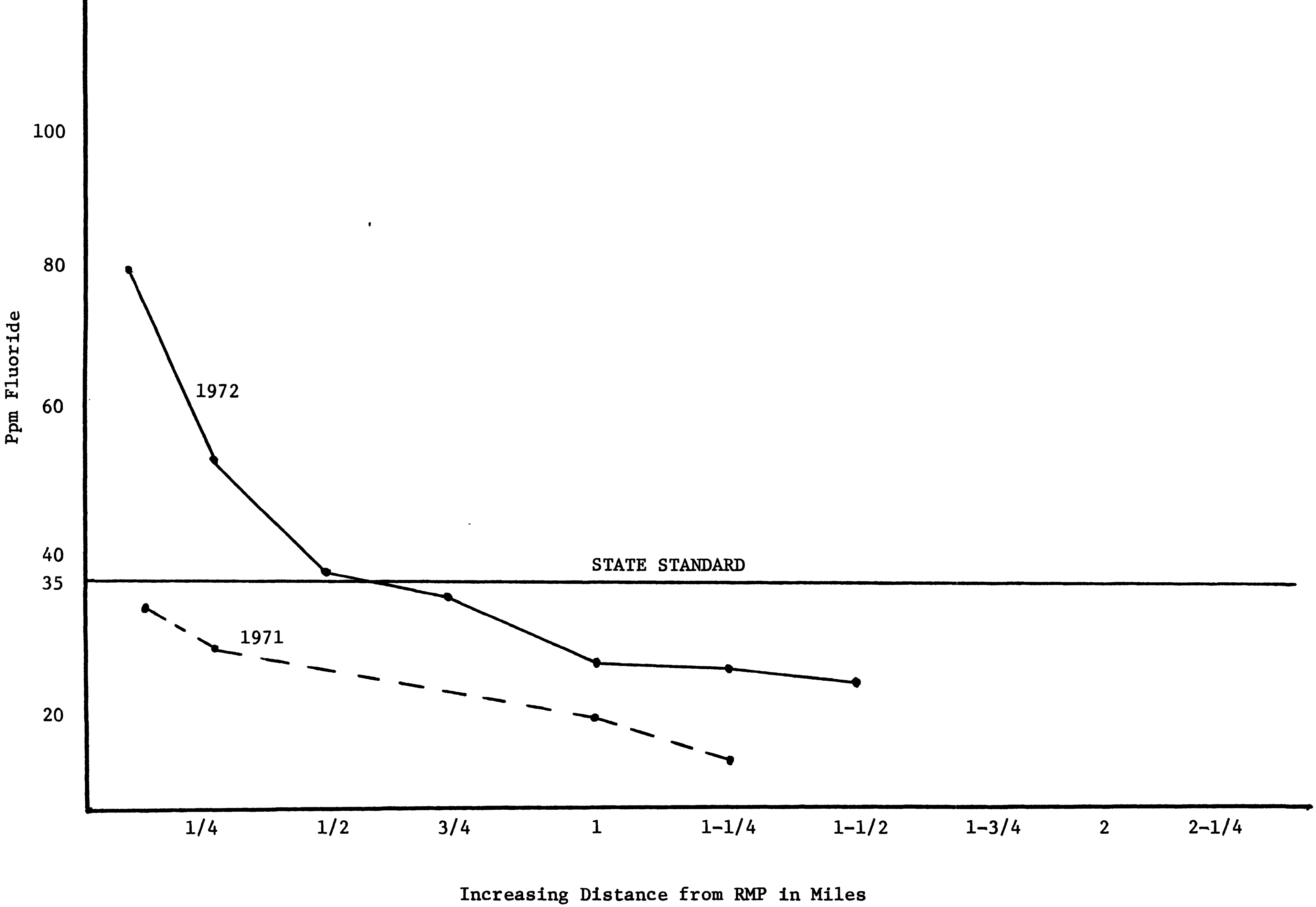


Figure 4. Ppm Fluoride in Forage, Plotted from RMP--Southeast

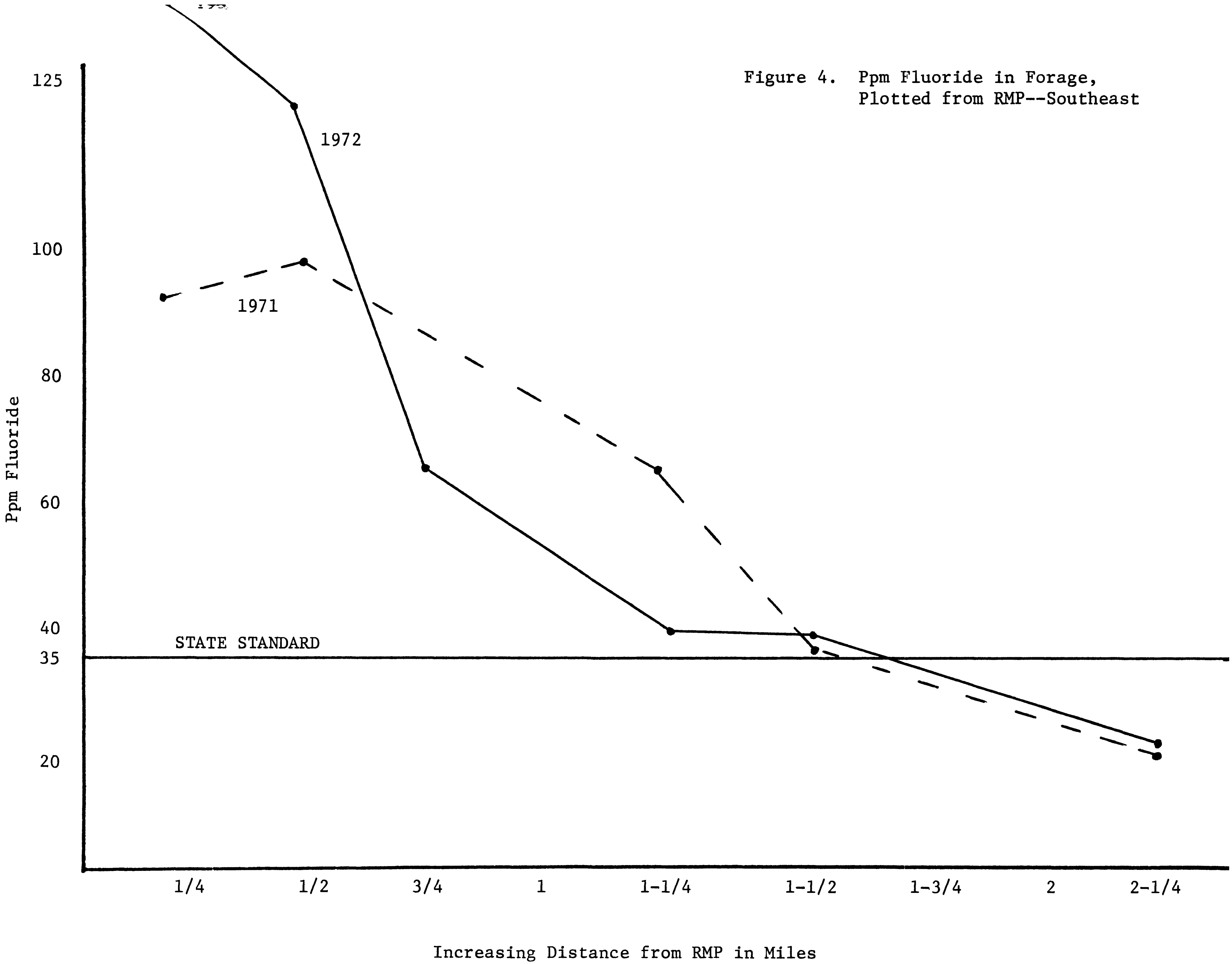


Figure 5. Ppm Fluoride in Forage, Plotted from RMP--Southwest

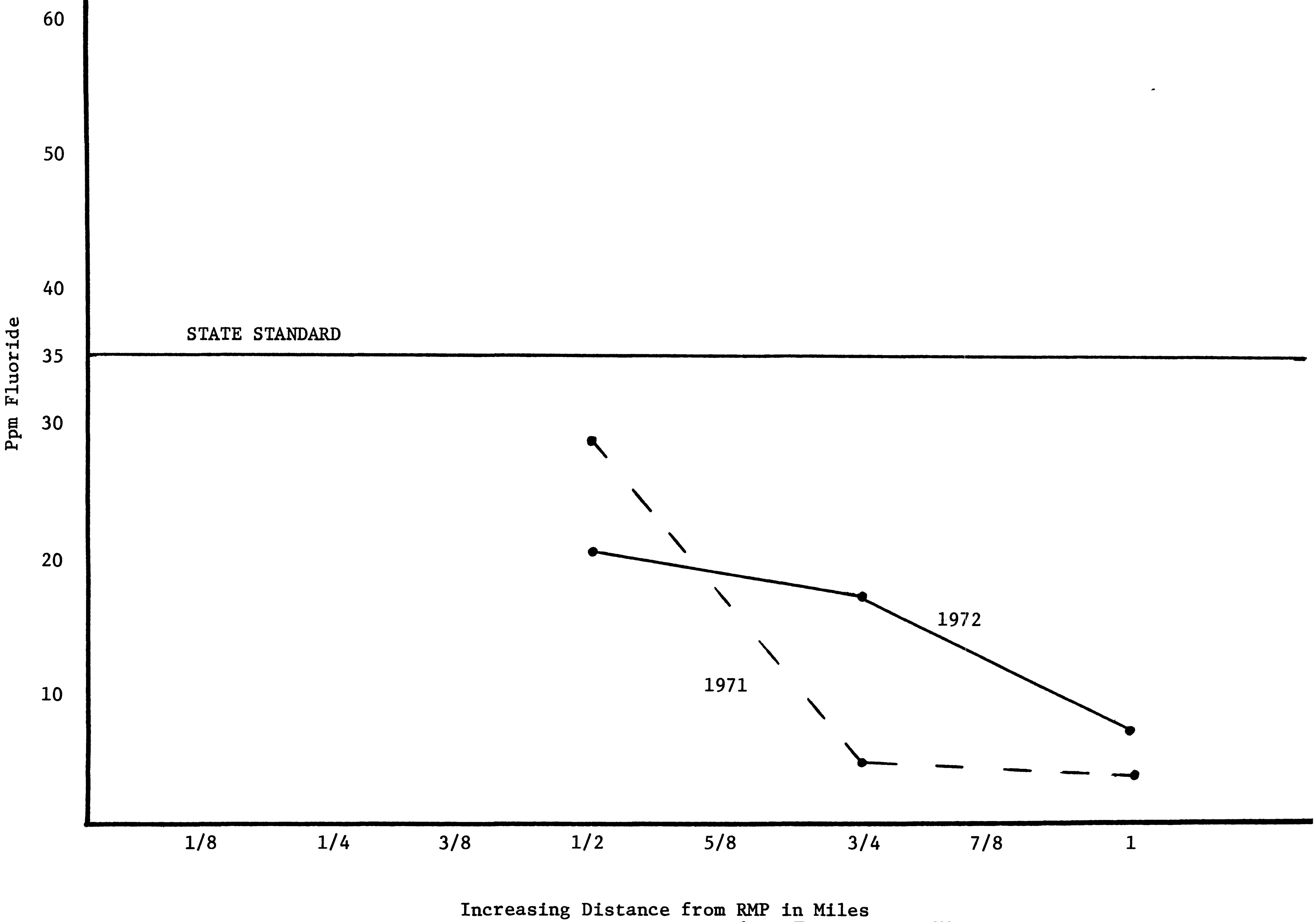
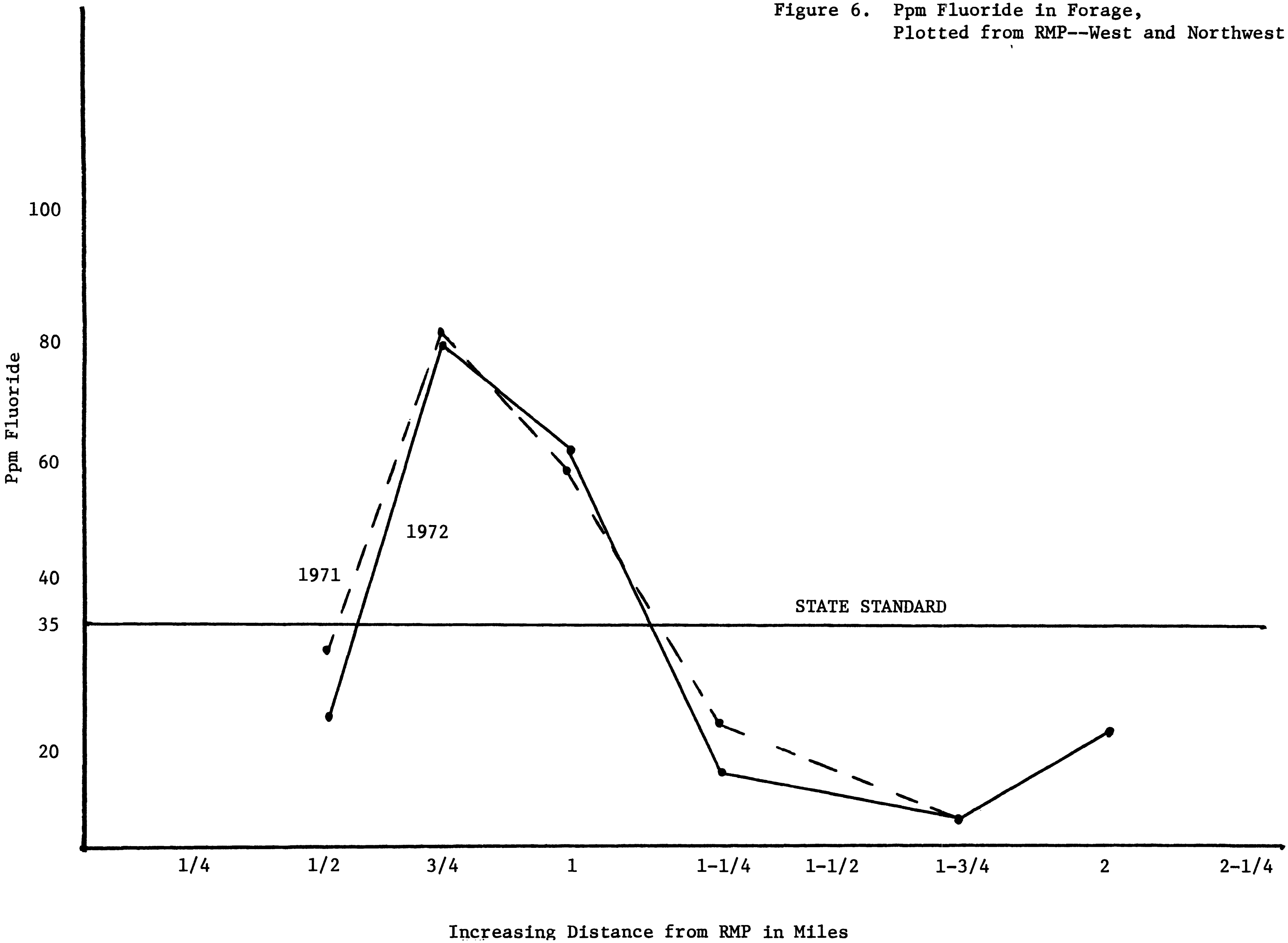


Figure 6. Ppm Fluoride in Forage,
Plotted from RMP--West and Northwest



The atmospheric patterns exemplified in Figures 2 to 6 can be summarized as follows: During the day air flow is predominately from the northwest with varying amounts to the north and east. There is little or no air flow to the south, but cold air drainage forces the fluoride emissions west and slightly north. Fluoride levels in vegetation are increased where these air masses meet elevated topography as a result of the greater exposure time to, or the increased concentration of, fluoride.

D. <u>Isopol Map of Fluoride Distribution--1971 and 1972</u>

The pattern of air movements described above can also be illustrated when isopol maps of fluoride distribution are constructed (Figures 7 and 8). Clearly, the state standard of 35 ppm fluoride in forage is being violated over a considerable area although the extent of the violation is more limited than in the past (Gordon, 1970). A comparison of the two figures also reveals an obvious change in fluoricity in 1972 as does Table 4.

The differences in 1971 and 1972 fluoride levels can be attributed to combinations of three variables: 1) slight changes in prevailing wind directions; 2) differences in exact collection sites and species sampled; and 3) increased fluoride contamination. The first is due entirely to factors beyond the control of the experimenter, and the second could have been controlled by more exacting experimental design, though in some instances physical limitations of certain environmental parameters made this impossible. Increased fluoride contamination can only be explained by some operational change in RMP.

In 1972, unlike 1971, RMP processed 50 percent local Montana phosphate ore and 50 percent phosphate ore from Florida. In 1971, all the ore was of Florida derivation (Rhodes, 1972). The fluoride content of Montana phosphate

Figure 7. Isopol Map of Fluoride Contamination in the Garrison Area--1971

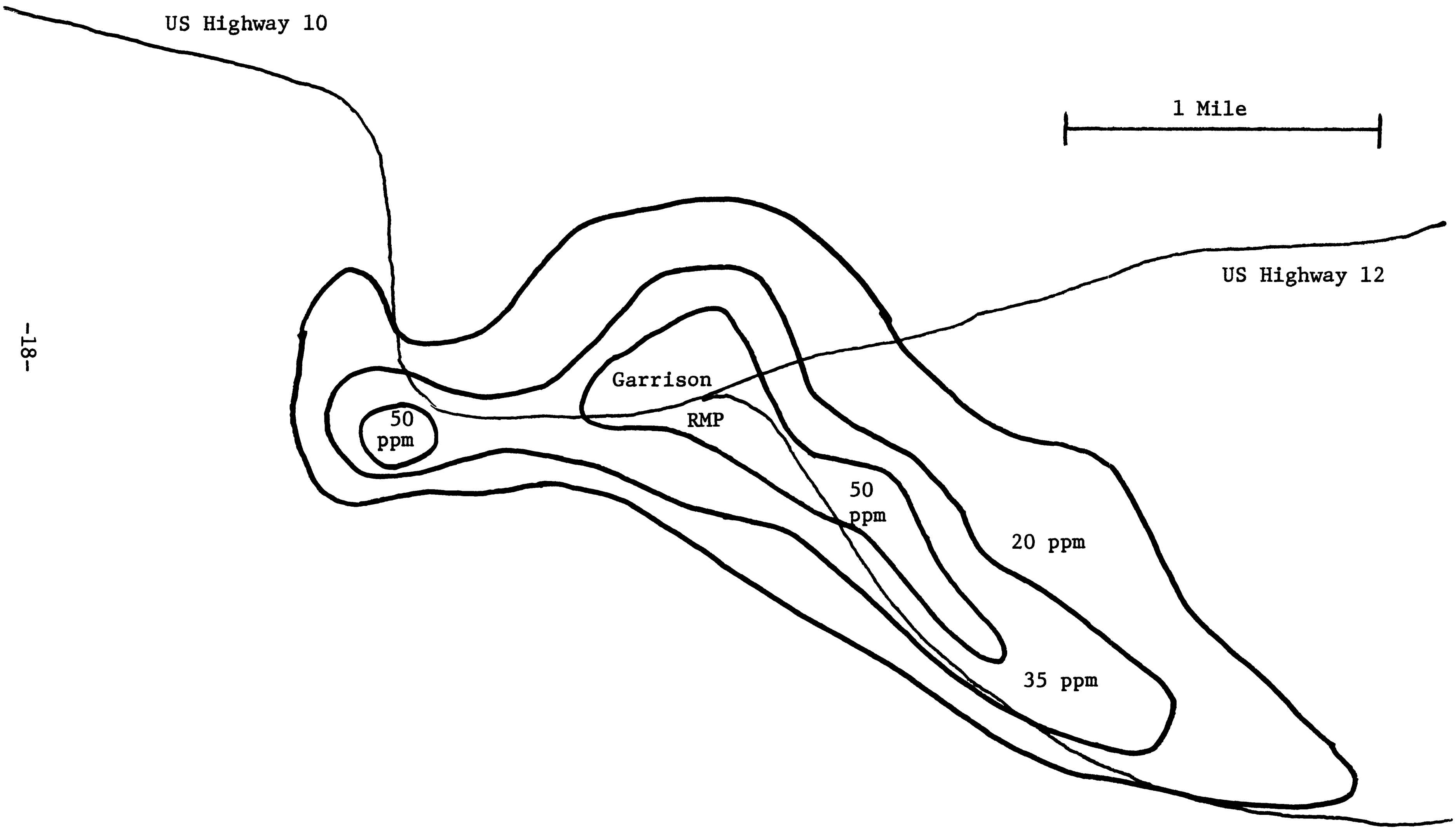


Figure 8. Isopol Map of Fluoride Contamination in the Garrison Area--1972

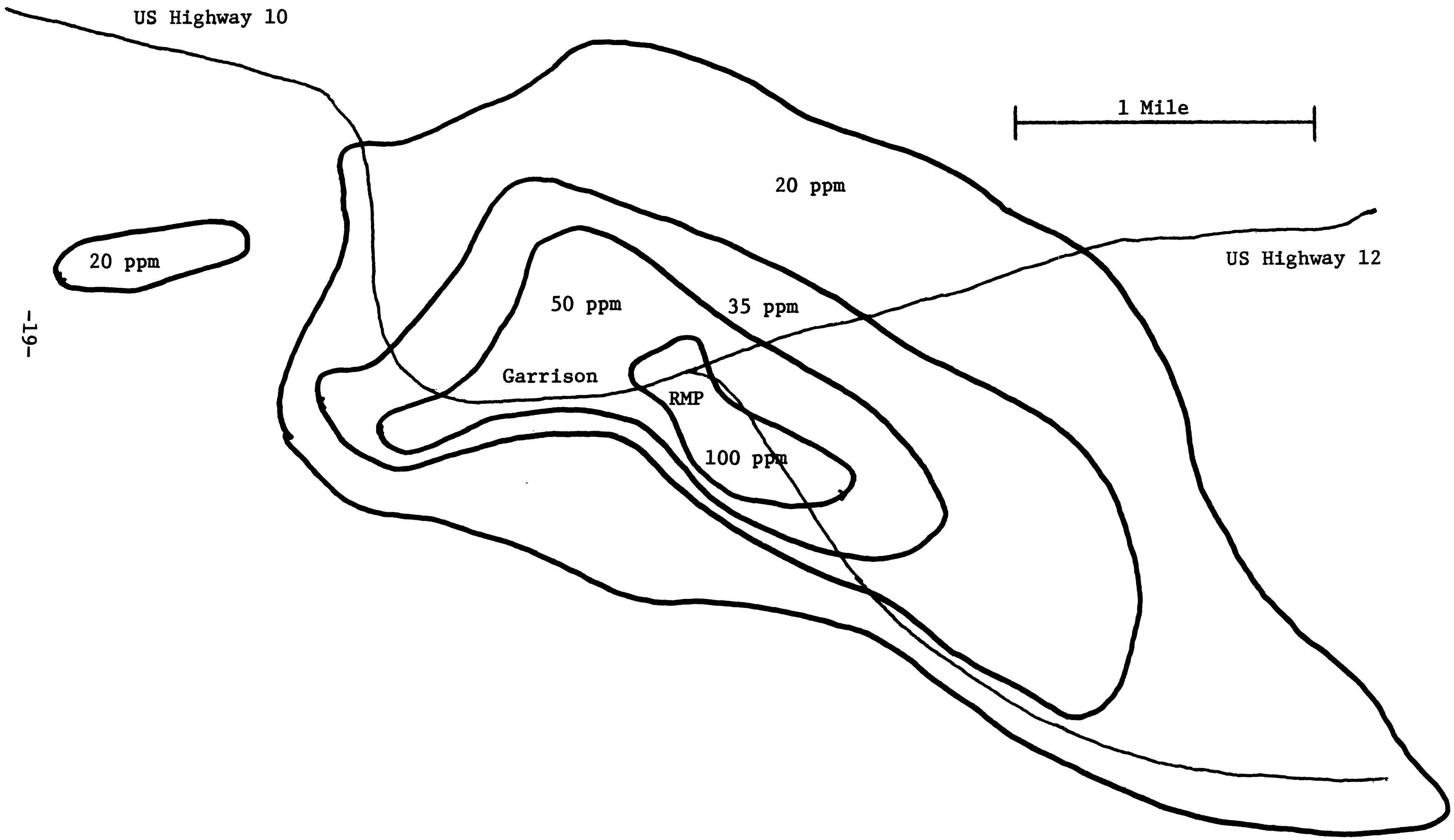


TABLE 4--PPM FLUORIDE IN VEGETATION SAMPLES OBTAINED AT EXACT SAME COLLECTION POINTS--1971 AND 1972

	1971 Ppm Fluoride	1972 Ppm Fluoride	Difference*	Percent*
Alfalfa	36	53	+17	+47
Lilac	58	57	-1	-2
Cottonwood	178	214	+36	+20
Smooth Brome Grass	68	204	+136	+200
Alfalfa	80	254	+174	+218
Bluebunch Wheatgrass	80	66	-12	-15
Juniper	74	97	+23	+31
Bluebunch Wheatgrass	27	59	+32	+119
Bluebunch Wheatgrass	46	81	+35	+76
Cottonwood	470	446	-24	-5
Lilac	72	71	-1	-1
Lilac	116	95	-21	-18
Cottonwood	100	250	+150	+150
Smooth Brome Grass	64	138	+74	+116
Cottonwood	100	168	+68	+68
AVERAGE	104	150	+46	+45

*Difference = (1972 value) - (1971 value)

*Percent = $\frac{\text{Difference}}{\text{1971 Value}}$

ore (from the Brock Creek area) is much greater than the percent of fluoride in the ore from Florida (Gordon, 1973; Silverman, 1973), a fact that may explain the 1972 increased fluoride pollution in Garrison. However, Mr. Bryce Rhodes, President of RMP, has stated that since his scrubbing operations are at 99.9 percent control efficiency, he does not think that the increased fluoride content of the phosphate ore would be responsible for the observed increase in fluoride pollution (Rhodes, 1972). Mr. Rhodes also stated that all other operational considerations have remained the same in 1972 as they were in 1971, and he gave no explanation for the documented increase in fluoride contamination. This leads one to a reconsideration of the question concerning the fluoride content of phosphate rock being processed.

Based upon the results of this study, it is concluded that the pollution abatement equipment currently in operation at RMP is not sufficient to prevent the fluoride accumulation in forage from exceeding the Montana state standard of 35 ppm, and that the fluoride contamination demonstrated in this study may be expected to be maintained until sufficient controls are installed. That is to say either RMP isn't really at 99.9 percent fluoride emission control or 99.9 percent control is not sufficient to meet Montana's 35 ppm standard in forage.

E. Small Mammals

All the small mammals collected, with the exception of shrews, were rodents--deer mice, chipmunks, and voles--and hence, herbivores (Burt and Grossenheider, 1964). The life expectancy of these mammals is less than one year. In fact, 90 percent are dead within one year of birth, and virtually none are alive after two years (Wright, 1971). In addition, the home ranges of these species are approximately 100 x 100 meters (Johnson, 1963); thus, they are localized indigenous animals, and the average fluoride levels in their femurs can be considered to be the result of the accumulation of one growing season. Consequently, they are invaluable as indicators of fluoride contamination.

The small mammal data in Tables 2 and 3 further support the conclusion that the Garrison area is fluorotic. The majority of the collections consisted of deer mice; hence, adequate sample size dictates that a detailed discussion of fluoride levels in small animals be confined to that species.

The decrease in fluoride concentrations in deer mice with increasing distance from RMP (Figure 9) illustrates the indigenous nature of this species and implies that fluoride concentrations in deer mice are dependent upon concentrations in vegetation. If this is so, then there should be a correlation between fluoride levels in indigenous vegetation and fluoride levels in deer mice. Figure 10, a plot of fluoride concentrations in deer mice versus fluoride concentrations in forage, shows that such a correlation does exist and is significant at the 0.001 level. However, this cannot be considered a direct relationship to the actual amount of fluoride consumed by the deer mice, since their normal diet consists mainly of seeds, nuts, insects, etc.--not forage (Burt and Grossenheider, 1964; Wright, 1971). Seeds and fruits in the Garrison area have been found to contain less fluoride than the foliage of their parent plants (Kay, 1972).

F. Continuing Fluoride Accumulation

In the Methods section, it was shown that coniferous trees and bunchgrass could be used to study continuing fluoride pollution. Assuming that the vegetation absorbs fluoride throughout its existence, one can deduce the relative severity of contamination during past periods. Both Douglas fir

Figure 9. Ppm Fluoride in Deer Mice from RMP--East Through Study Areas 1, 2, and 16

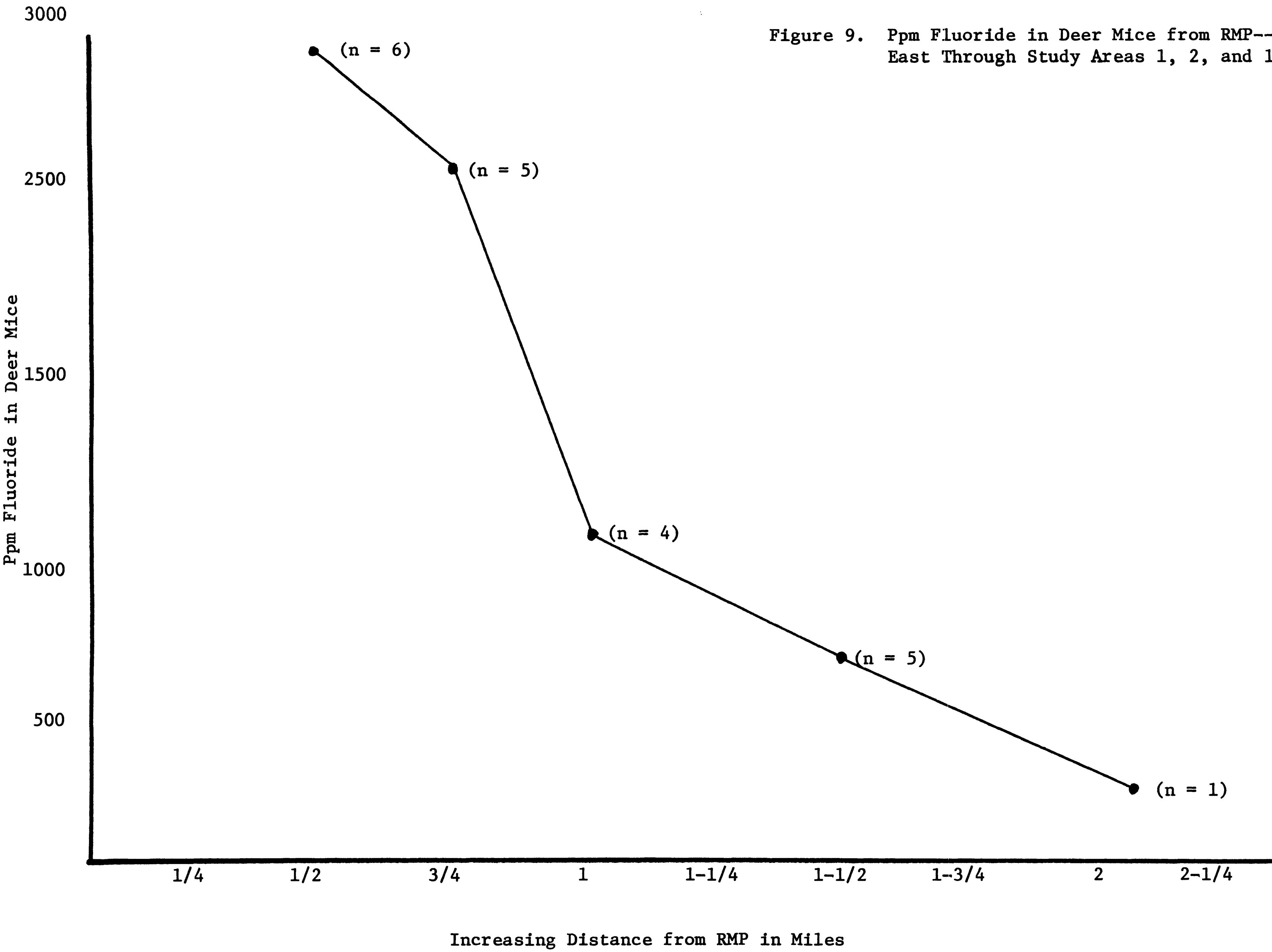
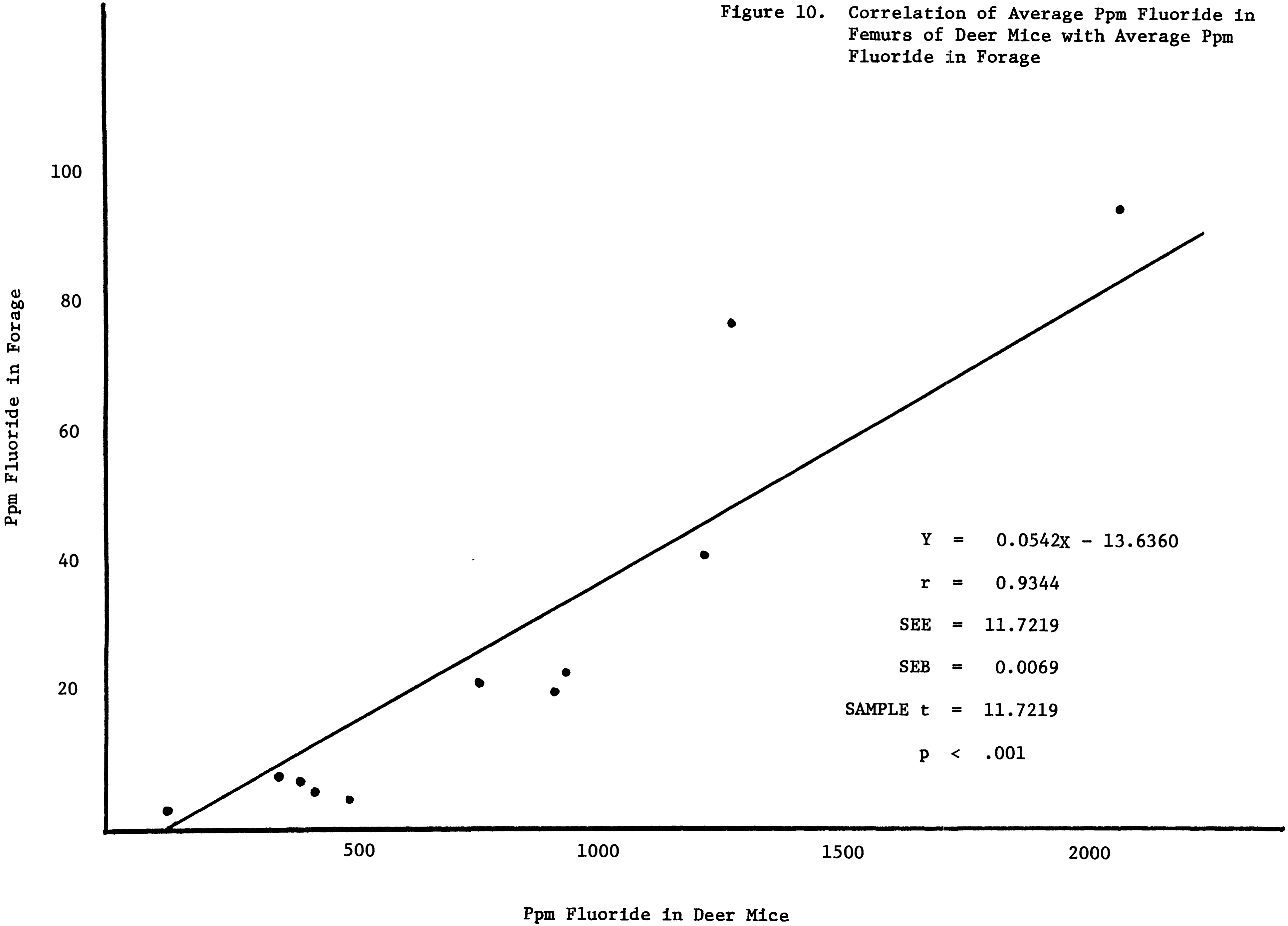


Figure 10. Correlation of Average Ppm Fluoride in Femurs of Deer Mice with Average Ppm Fluoride in Forage



and ponderosa pine were collected for analysis in this manner; however, the small sample size precludes a meaningful presentation of these data.

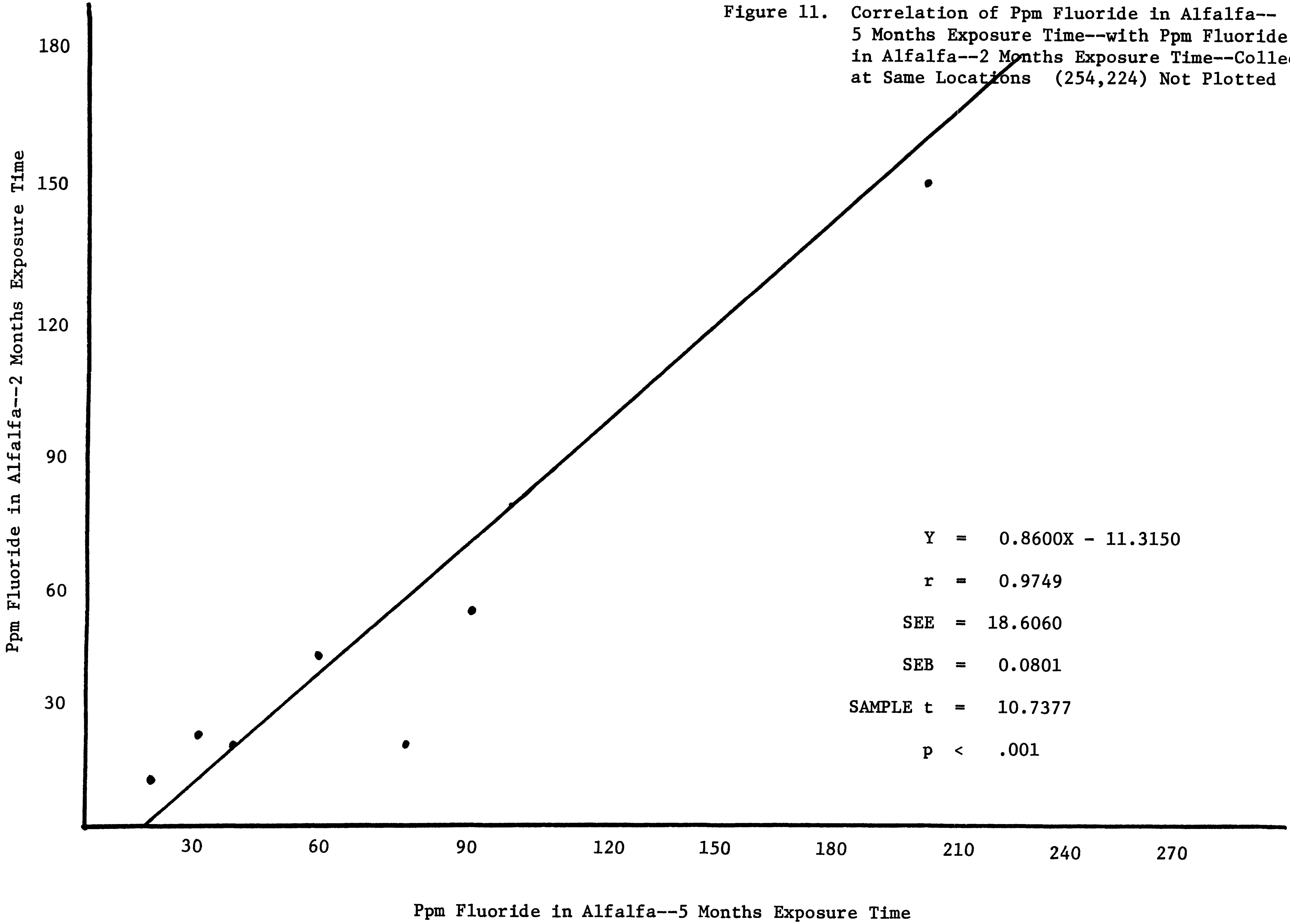
The average fluoride content of crested wheatgrass was dependent upon exposure time: 17 month exposure--121 ppm; 5 month exposure--68 ppm; and 1 month exposure--38 ppm. Since samples were collected within many study areas and varied in their exposure to the absolute level of fluoride contamination, exact rates of fluoride accumulation cannot be calculated. However, a linear relationship of exposure time to fluoride accumulation is not indicated.

By collecting alfalfa which had been cut during haying operations and regrown and alfalfa which was uncut, it was possible to obtain samples of the same species with different exposure times: uncut--5 month exposure; once cut--2 month exposure. Correlation of the data obtained is presented in Figure 11. These data clearly show that fluoride contamination has been occurring over a considerable period of time in Garrison.

G. <u>Species Specific Accumulation</u>

It has been demonstrated that discrepancies in fluoride results between different field collections from the same polluted area are often not due to incorrect fluoride analysis but rather to differences in the plant tissue tested within a given species (Gordon, 1970a). For example, one would obtain low fluoride values if one tested only the fall 1971 growth of crested wheatgrass or only once cut alfalfa. Similarly, since it is known that different plant species vary in their susceptibility to gaseous fluoride (National Academy of Sciences, 1971), it follows that low fluoride results could be obtained by sampling only species characterized by their inability to concentrate large amounts of fluoride, reporting their results

Figure 11. Correlation of Ppm Fluoride in Alfalfa--5 Months Exposure Time--with Ppm Fluoride in Alfalfa--2 Months Exposure Time--Collected at Same Locations (254,224) Not Plotted



under the general heading of forage or trees, and hence permitting the erroneous conclusion that no fluoride pollution exists.

Since as large a variety of species as possible was collected at each sampling point, a particular plant's accumulation of fluoride can be compared with that of other species located at the same collection point. This assumes that all plants at a collection site experienced an identical fumigation rate over time and that other environmental factors are equal.

The data on specific species accumulation is presented and discussed by individual pairing in Figures 12 through 18. If there is no species accumulation difference, the plotted points and calculated regression should depict a one to one ratio.

In Figure 12, alfalfa--smooth brome grass, both species can be classed as forage and both had the same exposure time. However, alfalfa appears to accumulate fluoride at a greater rate than does smooth brome grass, since alfalfa has a higher concentration in its tissues at the end of the growing season. A similar relationship has been reported for control fumigation experiments with alfalfa and orchard grass (Dactylis glomerata) (Hitchcock, et al., 1971).

In Figure 13, juniper--bluebunch wheatgrass, the observed may be a manifestation of a varying accumulation rate or of the fact that juniper represents a composite sample of more than one growing season. Further, the height of the collection point may be involved since juniper was sampled four to seven feet above the ground.

Similarly, greater accumulation of fluoride in juniper may be demonstrated by comparing the average juniper values by study areas with the corresponding forage parameters, as shown in Figure 14. Additionally, there is reason to believe that juniper itself should have been included in the average forage

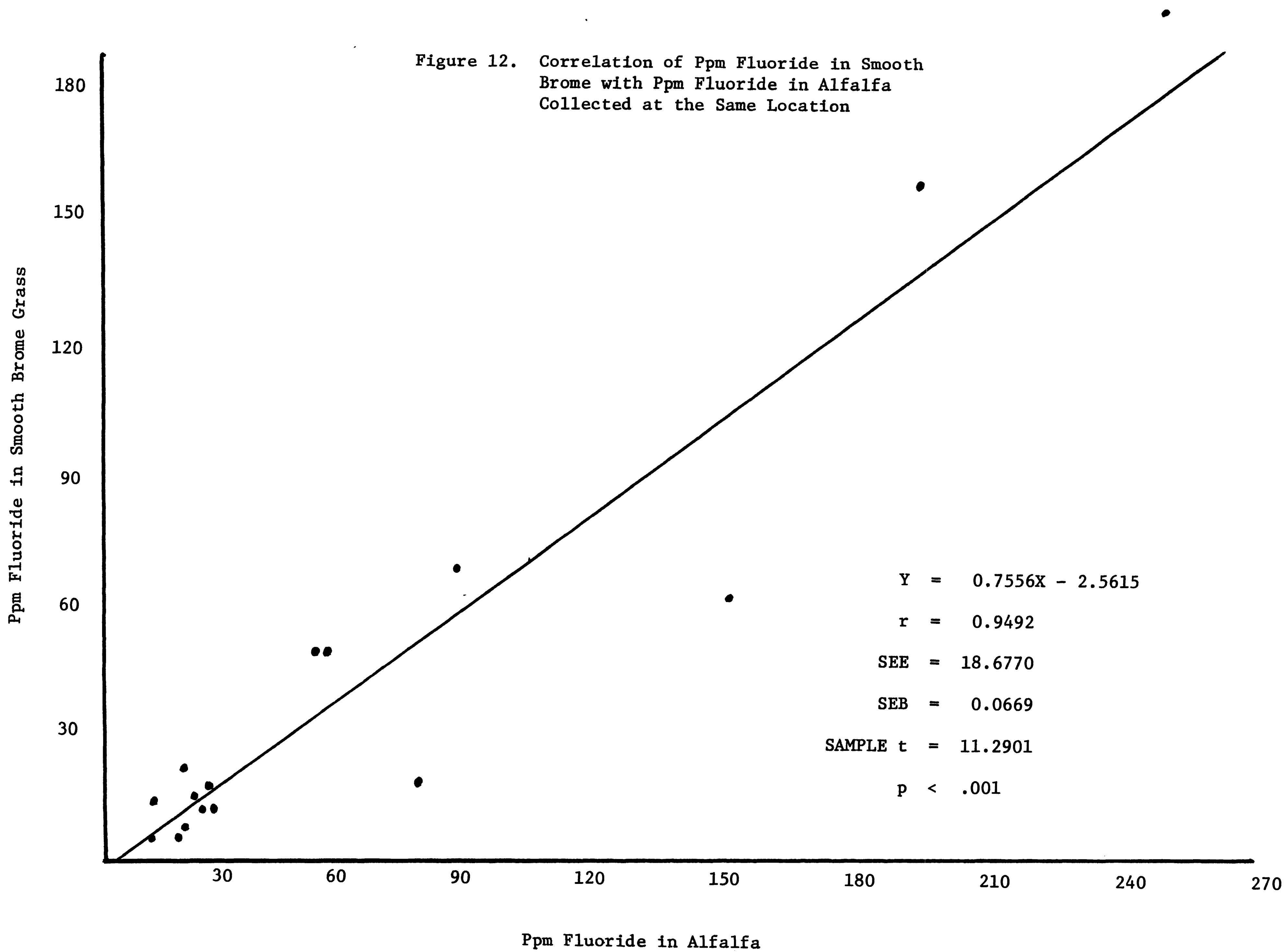


Figure 12. Correlation of Ppm Fluoride in Smooth Brome with Ppm Fluoride in Alfalfa Collected at the Same Location

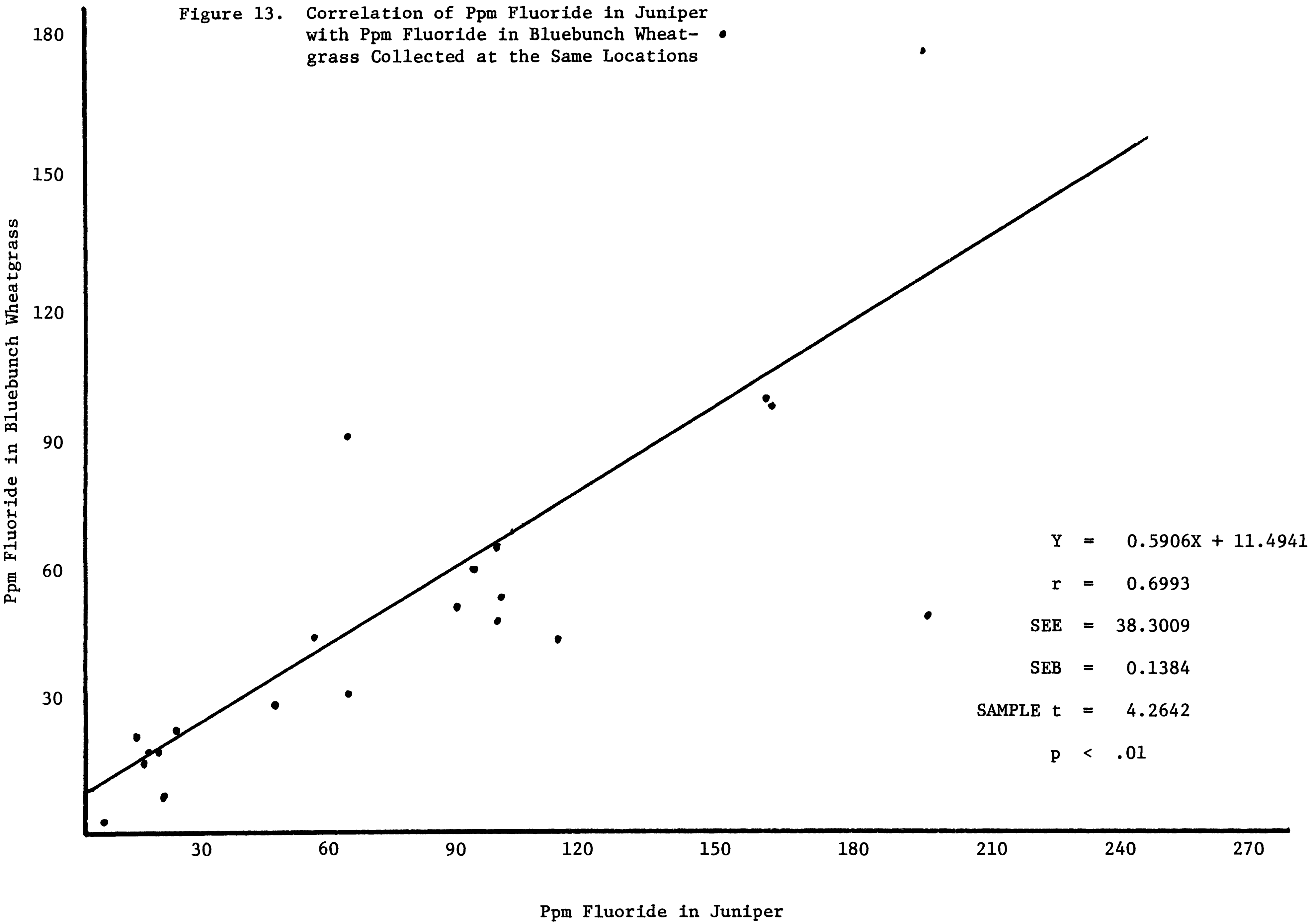
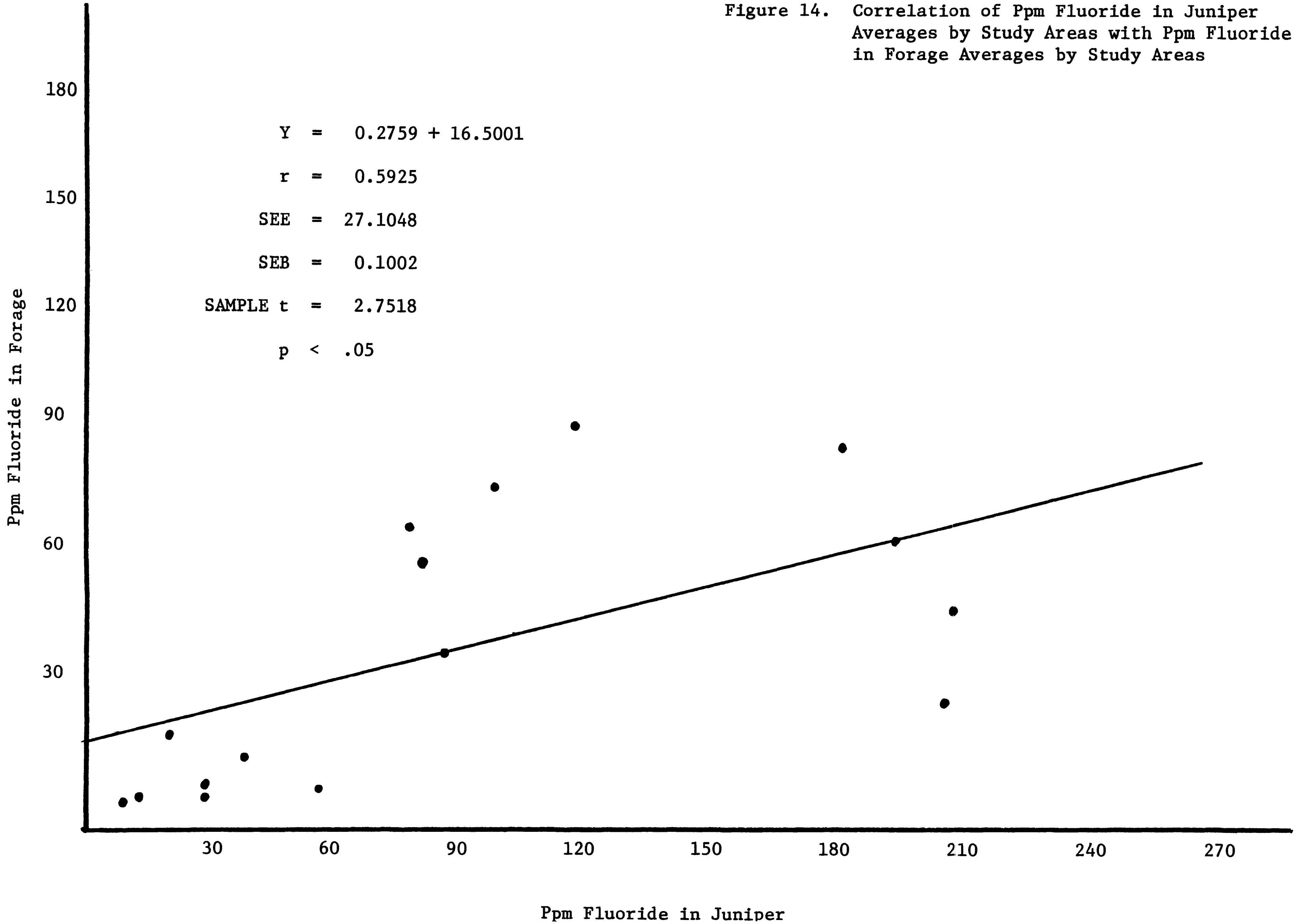


Figure 13. Correlation of Ppm Fluoride in Juniper with Ppm Fluoride in Bluebunch Wheatgrass Collected at the Same Locations

Figure 14. Correlation of Ppm Fluoride in Juniper Averages by Study Areas with Ppm Fluoride in Forage Averages by Study Areas



values, since, under certain circumstances, cattle as well as deer and elk consume quantities of this evergreen shrub (Eddleman, 1971). Thus, not only do the fluoride values for forage depend upon the forage species sampled, but on the very definition of forage itself.

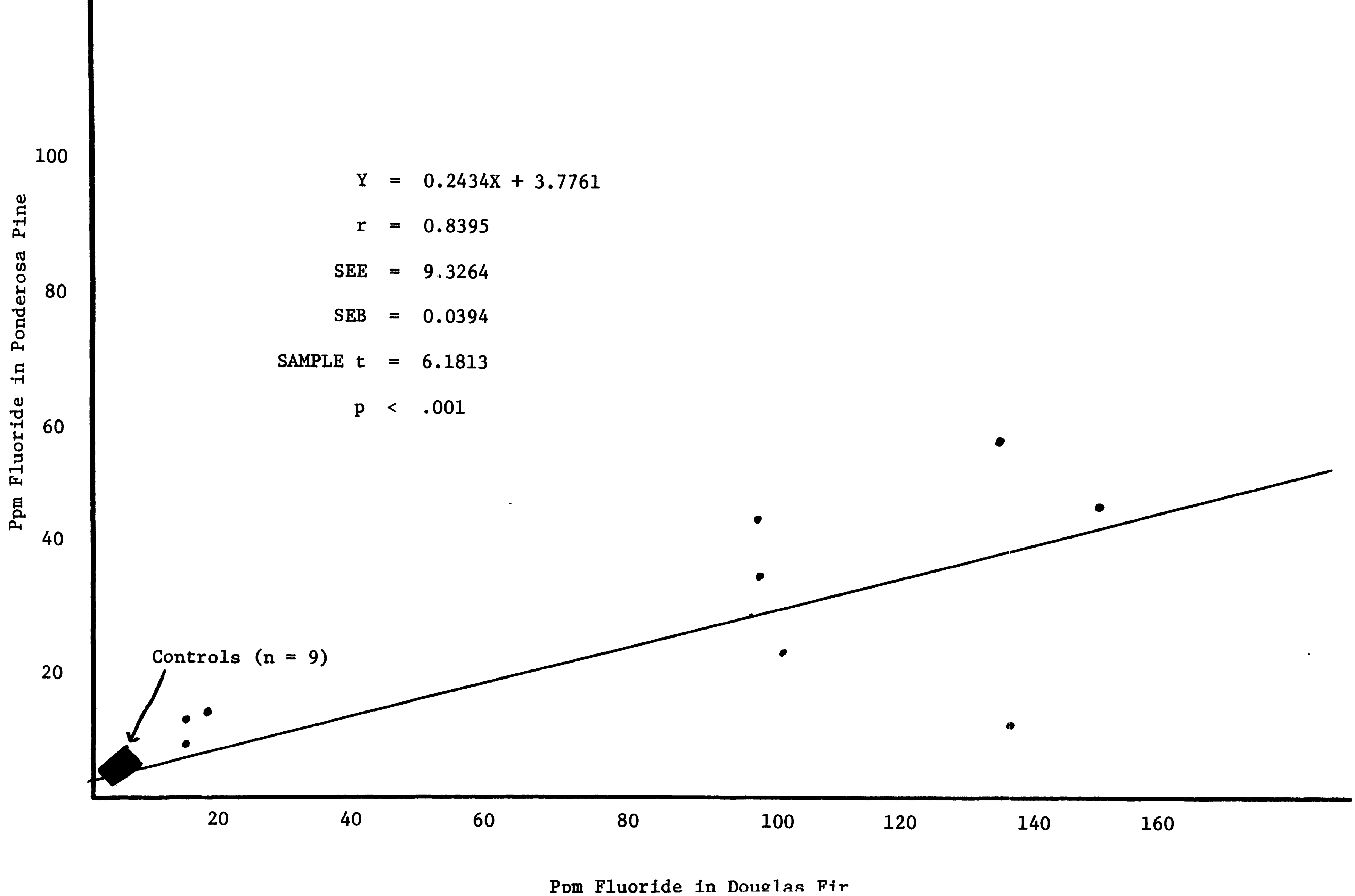
In Figure 15, Douglas fir--ponderosa pine, the accumulation rate of fluoride in Douglas fir is approximately four times that of ponderosa pine over the range of fluoride concentrations sampled. This phenomenon is no doubt physiological in origin and may be related to the fact that ponderosa pine is more susceptible to fluoride-induced needle damage than is Douglas fir (Gordon, 1973).

In Figure 16, cottonwood--alfalfa, and Figure 17, cottonwood--smooth brome grass, it is apparent that cottonwood accumulates fluoride a little more readily than does alfalfa. This same trend appears when smooth brome grass is plotted against cottonwood but to a more marked degree, which would be expected since smooth brome accumulates less fluoride than alfalfa (Figure 12). This may be a physiological response or it may be due to the height of cottonwood, exposing its tissues to greater amounts of fluoride.

The higher accumulation rate of cottonwood can be further demonstrated by comparing average fluoride parameters by study sites with the appropriate values for forage, as shown in Figure 18. Therefore, cottonwood is a more sensitive indicator of total environmental fluoride contamination than is forage, and it most clearly demonstrates the presence of fluoride pollution.

In summary, the exact nature and magnitude of the species differences are impossible to quantify, since variables such as soil type, exposure patterns, and physiological differences between species undoubtedly interact to determine accumulation rates of fluoride. Furthermore, the magnitude of these differences and perhaps even the dissimilarities themselves are wholly

Figure 15. Correlation of Ppm Fluoride in Douglas Fir with Ppm Fluoride in Ponderosa Pine Collected at the Same Locations



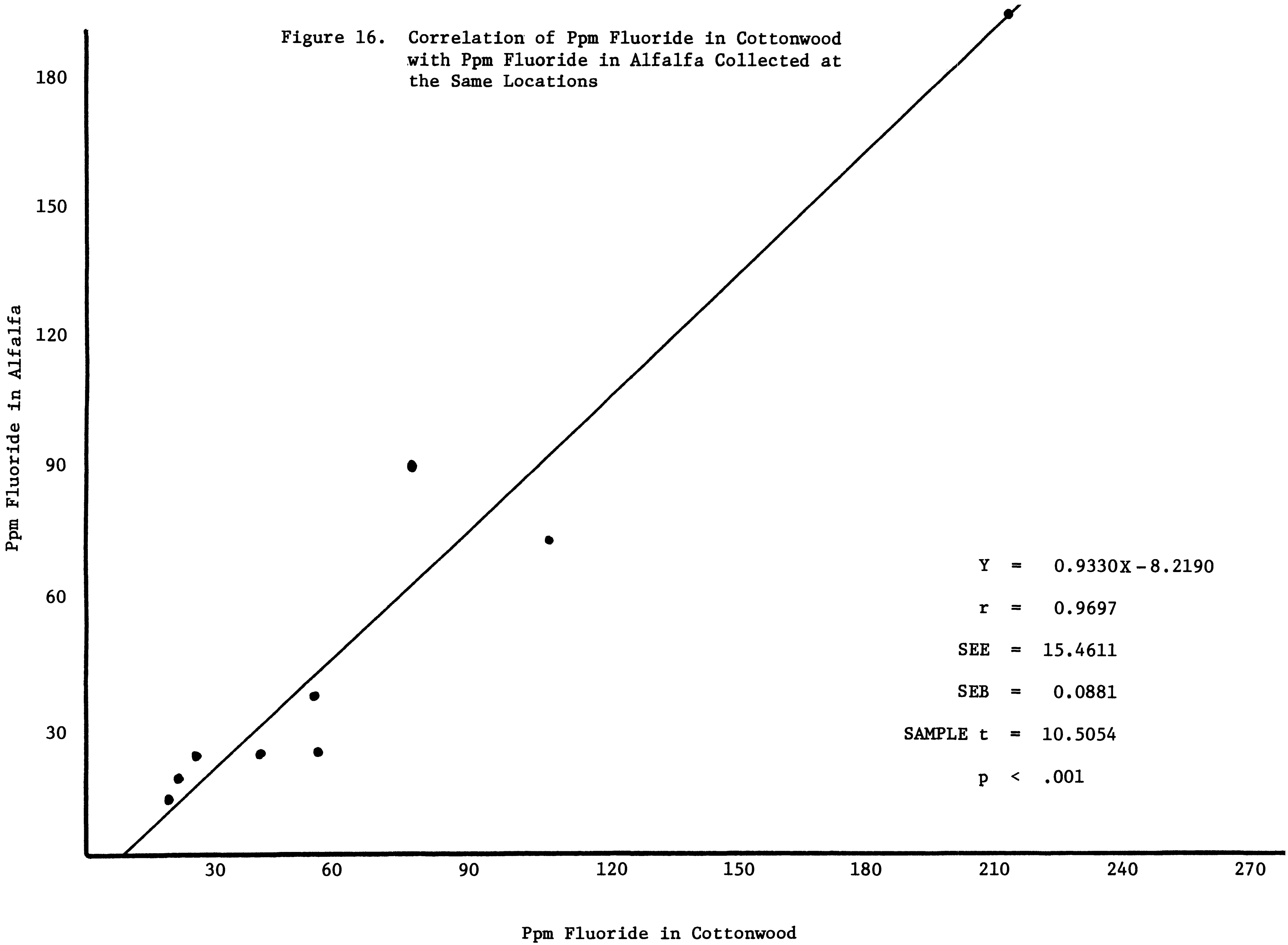


Figure 16. Correlation of Ppm Fluoride in Cottonwood with Ppm Fluoride in Alfalfa Collected at the Same Locations

Figure 17. Correlation of Ppm Fluoride in Cottonwood with Ppm Fluoride in Smooth Brome Grass Collected at the Same Locations (470,54), (476,96), (446,96) Not Plotted

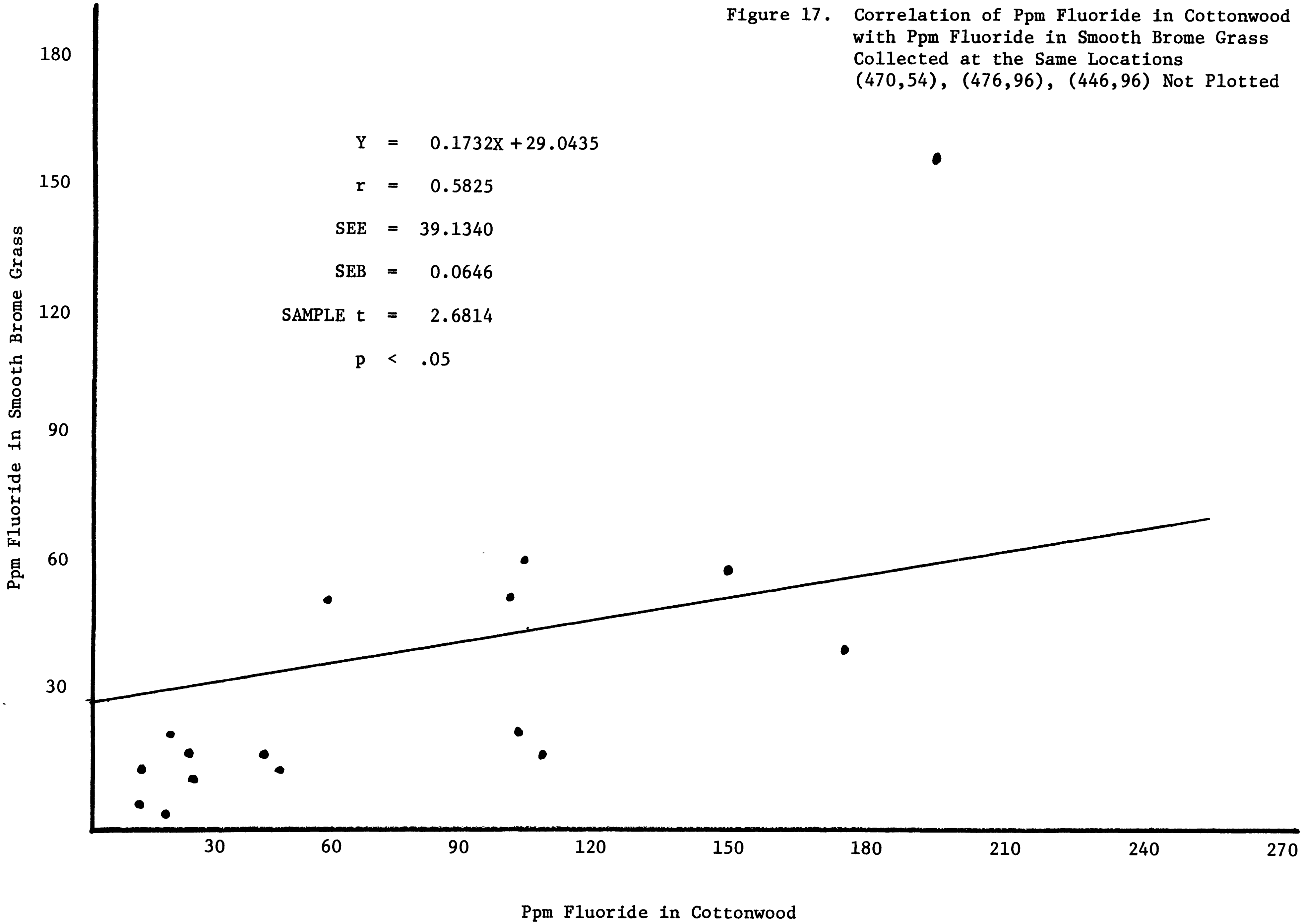
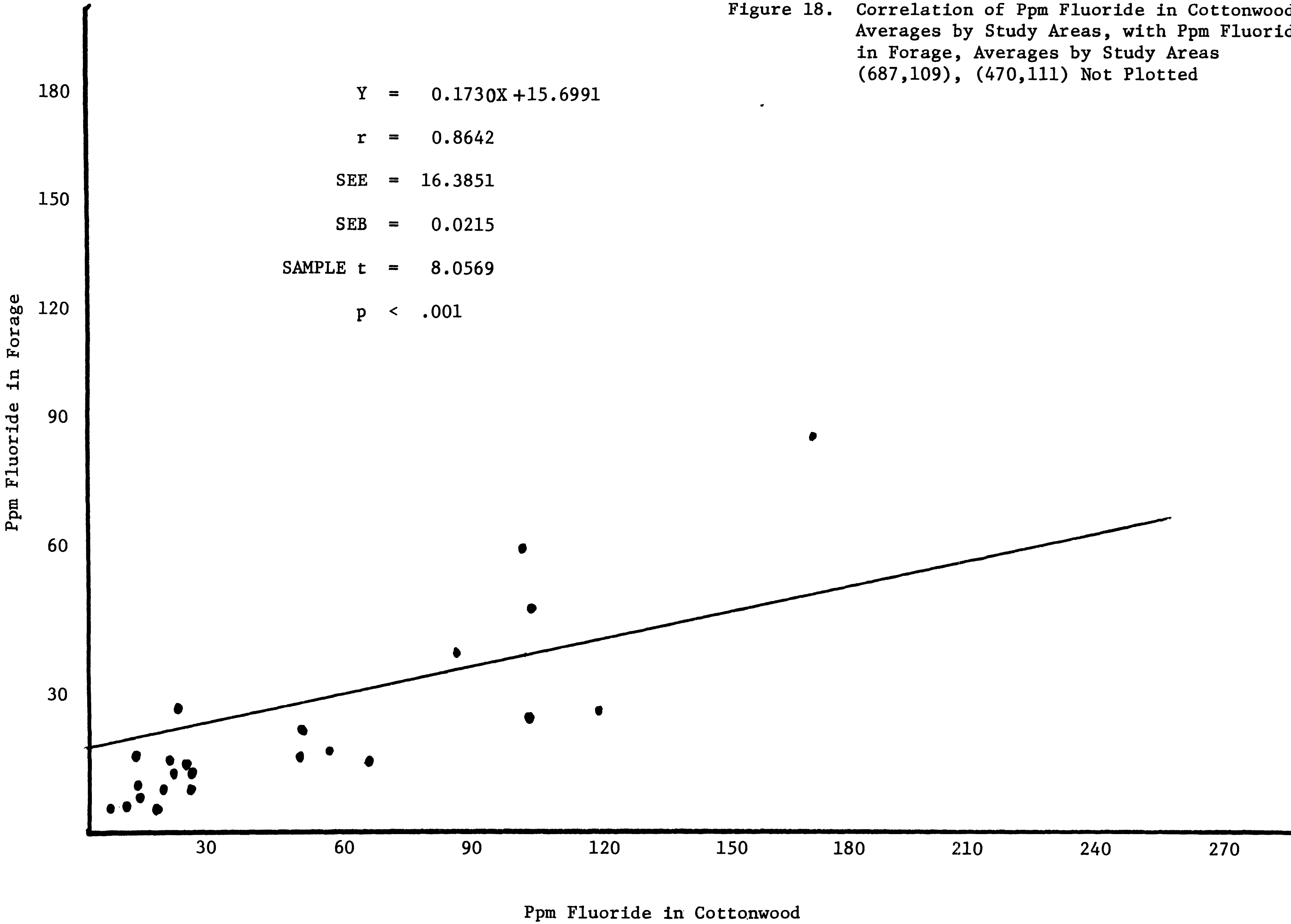


Figure 18. Correlation of Ppm Fluoride in Cottonwood, Averages by Study Areas, with Ppm Fluoride in Forage, Averages by Study Areas (687,109), (470,111) Not Plotted



applicable only to this study, due to the fact that various habitat conditions and geographic considerations may also affect accumulation rates.

This study is only a preliminary inquiry, since only the physical location of individual specimens was considered. Nevertheless, these data lend credence to the suggestion that fluoride accumulation varies by species, and that all fluoride sampling, analysis, and reporting of results should be as species specific as possible.

SUMMARY

In the fall of 1971 and 1972, a study of fluoride contamination in the vicinity of Garrison, Montana, was conducted. The objective of this study was to determine the extent and severity of fluoride pollution in the area by assaying the fluoride content of indigenous flora and fauna and thereby determining the effectiveness of Rocky Mountain Phosphate's air pollution control equipment. Vegetation samples including forage, shrubs, and coniferous and deciduous tree species were collected throughout the study area, as were various species of small mammals, in a directional pattern. Fluoride analyses were performed on these samples and on control samples collected throughout western Montana.

The majority of the vegetation was collected and processed for analysis by individual species, thereby allowing comparison of the ratio of fluoride accumulation between species. Correlations between fluoride levels in vegetation and small mammals were also performed. Further, isopol maps of fluoride concentrations in vegetation were constructed.

CONCLUSIONS

1. Control plants average less than 5 ppm fluoride. To avoid overlap, 10 ppm fluoride was used as the dividing line between unpolluted and contaminated areas.

2. Femurs of control animals average 156.7 ppm fluoride, with 200 ppm fluoride employed as the control baseline to provide a degree of latitude.

3. In analyzing vegetation, the total study area was found to be fluorotic with decreasing fluoride levels as distance from RMP increased, thus pinpointing the source of fluoride emissions. The prevailing southeast wind and coal air drainage to the northwest are manifested by extended directional fluoride contamination. The result of this is that RMP is in violation of the 35 ppm fluoride state standard in forage over a considerable acreage. See Tables 1 and 2.

4. Small mammals collected in the vicinity of Garrison show elevated fluoride levels which are directly correlated to the fluoride concentrations in their surrounding vegetation and distance from RMP. See Tables 1 and 2.

5. The accumulation of fluorides in plant and animal tissues amply demonstrates that RMP was emitting fluoride for the duration of the 1970, 1971, and 1972 growing seasons.

6. Fluoride accumulation varies by species even when the exposure time and site are the same. Therefore, sampling, fluoride analysis, and reporting of data should be as specific as possible to avoid biased interpretations. This is especially true when combining species under the heading of forage.

7. Based upon the results of this study, it is concluded that the pollution abatement equipment currently in operation at RMP is not sufficient to prevent the fluoride accumulation in forage from exceeding the Montana state standard of 35 ppm, and that the fluoride contamination demonstrated in this study may be expected to be maintained until sufficient controls are installed.

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